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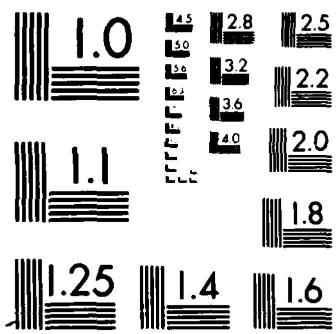
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

THE PERCEPTION OF THE HIGHER DERIVATIVES OF VISUAL MOTION

An Interim Scientific Report

1-1-83 to 12-31-83

During the period covered by this report we had nearly completed a computer program that allowed us to run an experiment on visual sensitivity to the higher derivatives of visual motion, completed the construction of ciruitry to operate CRT displays for acquisition of data for analysis, thus virtually completing the preparations for running a major experiment. We also conducted a number of pilot experiments to test ideas for additional work. At the end of the report period, the data from the experiment was actually underway and preparations were being made for data analysis. Also, additional control experiments were being designed. Our purpose in this report is to present the background of the experiment we performed and to provide a qualitative indication of the results, which will be presented in greater detail in the Final Report. We also provide some details concerning the computer program used in conducting the experiment. Those interested in obtaining complete documentation or a copy of the program itself on floppy disc should get in touch with the Principal Investigator.

DISCLAIMER NOTICE

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This report describes theoretical work involved in the early stages of this research effort and gives a brief review of the literature studied during that work. In particular, it reviews work on velocity difference thresholds, since several workers have concluded that judgmental comparisons of velocities at different times accounts for the human ability to discriminate between uniform linear motion in the frontal plane and acceleration. This conclusion is consistent with physiology, where motion detecting units are found to be sensitive to speed in specific directions, and none are known to be tuned to respond to particular rates of change of speed. No models of motion perception include provisions for detecting either changes in speed or changes in direction. Direct work on acceleration, however, is flawed. Hence, we devised a novel stimulus composed of sine wave gratings that drift at an average speed across the display. The speed is sinusoidally modulated, thus introducing acceleration and jerk (the third derivative). We also control spatial frequency, drift rate and luminance contrast. An experiment is described along with a computer program to permit conduct of the experiment.

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1. BACKGROUND:

Sensitivty to the motion of an image across the retina depends upon several factors, including the amount of time that the moving image is present, its luminance and contrast with respect to the background, and the presence or absence of stationary objects or of objects moving with different velocities. Many of these factors have been explored by researchers, and a good deal is now known about effects of other stationary objects, proximity of the moving object to stationary objects, luminance of the moving object, and so on (see Kaufman, 1974 for a review). We know far less about how such factors influence sensitivty to change of velocity (acceleration), or still higher derivatives of visual motion. The purpose of the experiment conducted during this phase of our program was to gain further insight into the factors that influence sensitivity to change of speed of an object moving in the frontal plane.

The amount of acceleration is the rate of change of velocity. Since velocity is a vector having both direction and magneitude, acceleration can be intorduced by changing either parameter. Thus, a target moving along a circular path may have a constant speed along the path, but it is still accelerating because it is always changing direction. A spot moving from side-to-side in a simple harmonic manner is also accelerating because it changes speed as well as direction as it moves. Alternatively, a spot moving in one direction accelerates if only its speed in that

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direction is changed. The present experiment deals exclusively with sensitivity to changing speed of a target moving in one direction in the frontal plane. This is but a first step toward further research which will be directed toward the more general problem of acceleration, including the acceleration introduced by changing direction of motion, and that of still higher derivatives of visual motion. One reason for this restriction is that extremely little is known about the visual processes involved in the perception of visual direction, while a good deal is known about mechanisms underling the perception of motion along a straight-line path. In fact, the existence of directionally selective cells ("analyzers") in the visual system was suggested by Sutherland in 1959 and subsequently confirmed in animal studies (Barlow and Hill, 1963; Hubel and Wiesel, 1962,1968). These units are selectively sensitive to edes and bars of particular orientations and moving in particular directions at right angles to their lengths. The waterfall illusion and related after effects are consistent with the view that such units mediate perception of motion when the stimulus translates in one direction or another across the retinal mosaic. It is worth noting that none of the models of motion perception that incoporate polarized motion detecting units, e.g., Barlow, Hill and Levick, (1964); Foster, (1971); Reichardt, (1961) attempt to deal with the detection of changing speed.

Since none of the motion sensitive units in the cortex seem to be particularly responsive to changes in the speed of a stimulus within their receptive fields, we are left with the problem of accounting for the detection of such changes in speed. This is one justification for studying difference thresholds for velocity. Such studies were carried out be Hick (1950), Notterman, Cicala and Page, (1960) and by Mandriota, Mintz and Notterman (1962), among others. This work was explicitly motivated in part by the assumption that detecting differences in velocity of targets moving at slightly different speeds at different times or places will clarify our knowledge of how the perceptual system processes acceleration.

Several investigators have addressed the problem of how humans perceive acceleration of a visual target directly. Gottsdanker (1956), who reviewed much of this literature, also conducted some of the more interesting of the relevant experiments.

In one study Gottsdanker (1952) moved a target along a horizontal path at a uniform speed and also at two different non-uniform speeds, i.e., positively accelerating and negatively accelerating. All targets dissappeared some time after motion began. While the target was moving, the subject tracked it with a stylus. The subject was required to continue tracking after the disappearance of the target. The hypothesis being tested was that the tracking of an accelerating target continue to speed up after the target disappeared. This hypothesis is based on the assumption that if the subject could sense acceleration directly, then he should be able to anticipate increased speed even after the target disappears. This hypothesis was not confirmed. In fact, after disappearance of the target it was tracked at a uniform speed which was approximately the same as the instantaneous velocity at the time of disappearance. These results led Gottsdanker to conclude that tracking was based on velocity or on aveage velocity during some time interval prior to the disappearance of the target. Furthermore, Gottsdanker proposed that subjects do not sense changing speed directly, but infer it by comparing velocity within one interval of time with velocity within some other interval of time. This view is consistent with the view that measurements of velocity difference thresholds can be of use in intepreting the responses of subjects to accelerating targets. Gottsdanker, Frick and Lockhard (1961) reported results using another paradigm, and these were consistent with the conclusion that acceleration is not sensed directly.

Subjects in the Gottsdanker at al. (1961) experiment compared a target moving with a uniform velocity in one run with an accelerating or decelearting target on another run, and had to decide on which run the motion was uniform. In terms of proportion correct choices, accuracy decreased as mean velocity increased. Discrimination was also adversely affected by a decrease in presentation time. Discrimination was found to be dependent upon the difference between initial velocity and final velocity of the accelerating or decelerating target. This is consistent with the notion that subjects simily compare the initial and terminal velocities to make the discrimination.

Rosenbaum (1976) dissented from the conclusion of Gottsdanker. He permitted subjects to see a moving target before it was occluded and then again after it was occluded. His subjects had to judge when an occluded target would intersect a visible marker in the path of the hidden target. This was done for targets having a uniform motion, and also for targets that were acclerating. Subjects appeared to be able to perform this task. Performance was most accurate for uniformly moving targets and for those that change speed slowly.

Some problems beset many of these earlier studies. An accelerating target moving across a field often moves so fast that it is virtually a blur before it leaves the field of view. In the velocity difference threshold experiments an abupt change in speed is sometimes introduced as it travels across the display. This introduces bother acceleration and jerk, and the effects of these higher derivatives are controlled for. Also, when a target moves at two different speeds at different times, the factor of memory must be taken into account. Finally, some papers have reported effects of practice, and this might be necessary to detect acceleration per se.

2. EXPERIMENTS:

The experiment being worked on at the end of this reporting period, was designed to include factors that were not explicitly incorporated in earlier work. While these included stimulus parameters such as spatial frequency content of the target and its contrast, the most important has to do with time during which the moving target os visible.

As intimated in the BACKGROUND section, the stimulus in the cited work was usually a spot that moved across a limited display area, either at a uniform rate or with some change in speed as it moved. This spot had an initial velocity and a terminal velocity, and sometimes one or the other was so fast that the spot was a streak. (This type of clue could govern the judgment, thereby obviating the need to use information regarding acceleration per se). Moreover, the limited field of view necessarily limited the time during which the motion could be observed. To get around these problems we designed another type of stimulus.

The stimuli of these experiments are computer generated gratings created by sinusoidally varying the luminance of a raster across the screen of a CRT. The display itself subtended 8.4 deg horizontally and 7.2 deg vertically with the subject seated at a distance of 140 cm. Three different spatial frequencies are used. These were 0.5, 2.0 and 4.5 c/d. The average luminance of the screen was set at 40 cd/m*2, and the luminance contrast had one of two values, namely 0.2 and 0.5. The gratings drifted across the screen with one of three different average velocities, i.e., 0.5, 2.0 and 5.0 deg/sec. The direction of motion was either to the left or right, with direction varied at random but frequently enough to prevent adaptation to one direction of motion. Luminance contrast was also randomnized from one presentation of a stimulus to another. Finally, the speed of the grating was sinusoidally modulated at one of four different modulation frequencies. These were 1,2,4 and 6 Hz.

Figure 1 provides a graphical means for visualizing the essential properties of the stimulus. The upper tracing shows how the velocity of any point on the grating varies over time. The sinusoidal variation in in velocity has a frequency which, in this experiment, has one of the four values mentioned above. The fact that the sinusoid is placed above the X axis of this graph is intended to imply that there is an average speed (greater than zero), and this average speed is modulated by the sine wave. The net effect is a grating that always drifts toward one side, but alternately slower and faster than its average drift rate. If the sine wave were below the X axis it would suggest that the net drift is in the opposite direction.

The second graph describes how the velocity is changing as a function of time when it is made to vary sinusoidally. Hence, this is the second derivative of position (velocity is the first derivative), or acceleration. It is always true that the derivative of a sine wave is a cosine wave. Finally, the third graph shows how the aceleration itself changes as a function of time. This is the third derivative (jerk), and it is always a negative sine wave relative to the sinusoidally varying first derivative.

The purpose of the experiment was to determine the sensitivty of the subject to non-uniform motion of a grating. Hence, the subject had to discriminate a grating whose speed was being modulated from one that was moving with a uniform speed, 75% of the time. The stimuli were presented for 2 sec each in pairs which were alike in all respects except that the speed of either the first or second stimulus was sinusoidally modulated. The subject had to choose which of the two intervals contained a grating moving in a non-uniform manner. High levels of modulation were used in the early trials, and this depth of modulation was reduced by half ob succedding trials. Thus, a modified staircase procedure was employed, with four staircases interleaved in any block of trials to determine the amount of modulation of speed needed to detect nonuniformity of motion 75% of the time.

Several approaches to evaluating data from this experiment may be taken. First, the simple difference between the peak velocity of a grating and its average velocity coiuld be used as an index of performance. This is referred to as "velocity amplitude". Second, by analogy with the Michelson contrast used to describe sinusoidal variations in luminance, the difference between peak and trough velocities at threshold divided by their sum can be used as a measure of performance. The reciproacl of this measure defines sensitivity in a manner analogous to that used in contrast sensitivity experiments. Moreover, this measure is equivalent to the classic Weber fraction. A third measure is that of the maximum acceleration of the grating at threshold, which is proportional to the product of the velocity amplitude and modulation frequency.

As already indicated, the experiment described here was not completed at the end of the period covered by this report. An account of its outcome will be included in the Final Scientific Report.

3. "CSICK" PROGRAM:

It is important to note that a great deal of effort was expended in developing the software to generate displays, present stimuli in a two-interval forced choice manner within the framework of a (four interleaved) modified staircase method, aquire and store data concerning the switch pressed by the subject and allocate it into the categories of "right" and "wrong", and so on. In fact, we encountered major problems in attempting to do this on our own. Therfore, we enlisted the help of Dr. Aries Arditi who bore the major responsiblity for developing suitable software. This work is virtually finished. A copy of a document describing the csick program is appended to this report.

(NOTE: Since this report was compiled aft.. the end of the official reporting period, it is worth noting that the experiment described above is complete and was submitted for publication.)

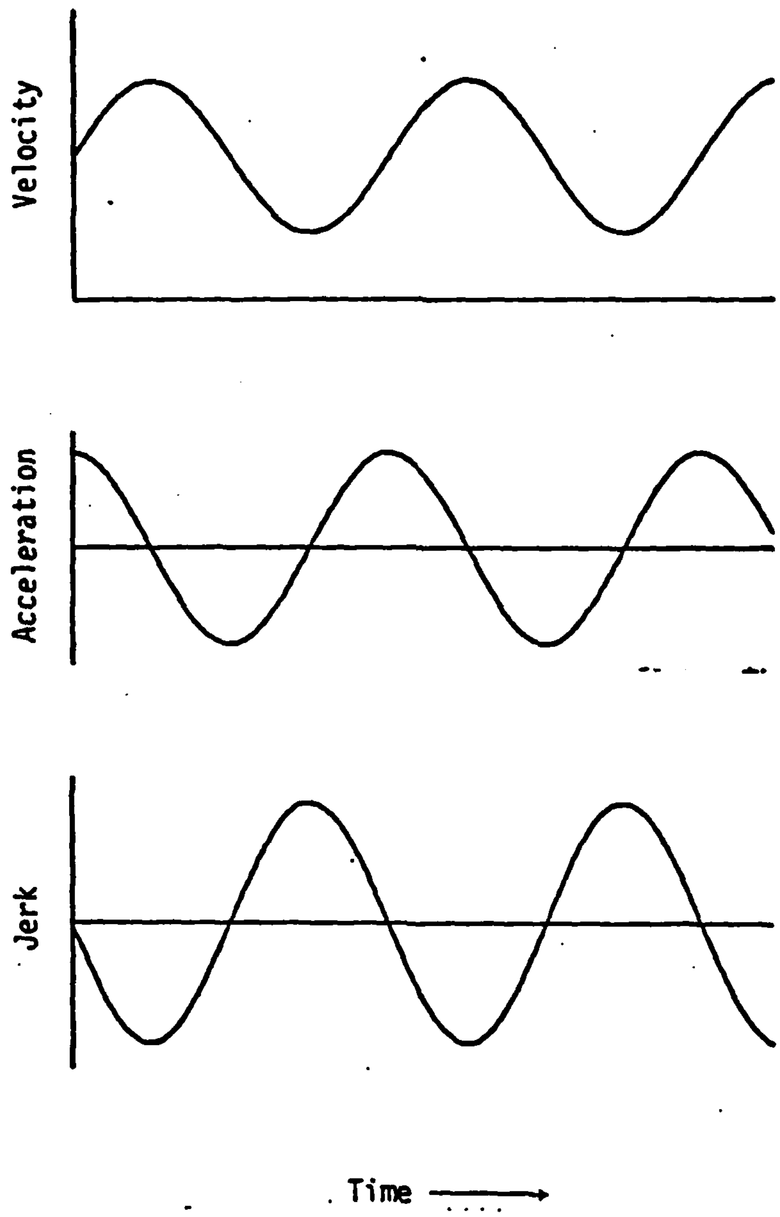

Figure 1 (see text)

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APPENDIX

Notes Describing the CSICK Program

as of 22 February 1983

The CSICK package consists of several files:

CSICK.FCL:

The main program

NSETUP.FCL:

A file called by the beginning of CSICK which sets up several default parameters and addresses used by the program. For example, the base address of the area of the fx buffer holding the stimulus parameters, the offsets into that space at which the individual stimulus parameters reside, some other junk, and a small overlay on block 0 of the main program. Note that not all of this file contains line numbers; the portion that doesn't is executed in immediate mode. Thus to edit this file, you cannot use FOCAL's editor. You must use an ordinary text editor.

(NPNEWS, NPLIBS).FCL:

These files are overlays to block 18, which is the block which creates (NPNEWS) a new library parameter file, or calls up an existing (PLIBS) one. Don't worry about block 18, it is very dense and incomprehensible. But these facts should be born in mind: 1) CSICK contains the NPLIBS version (i.e. NPLIBS can be thought of as the default overlay). This is important because if you edit CSICK, you must be sure that you have not overlayed NPNEWS. So, if you are running CSICK and at the same time making changes to it, make sure that before you save the new version, you "l g NPLIBS" as well. By the way this is true of block 0 as well: Recall that NSETUP.FCL has an overlay to block 0. There is a file called 0.fcl which you can "l g" before saving as well.... 2) If you get an error messasge from a line in block 18, you CAN simply "GO" to that or a previous line in 18. This is possible because block 18 is not called via a "DO" statement. Rather, it is entered and exited with "GOTO" statements (See line 18.80).

FX(413,BASE ADDRESS OF SPACE LIST, SPATIAL FREQUENCY, LUMINANCE CONTRAST ATTENUATION, AVERAGE DRIFT FREQUENCY, BASE ADDRESS OF DRIFT MODULATION WAVEFORM,DRIFT MODULATION, DRIFT MODULATION FREQUENCY,FRAMES)

IMPORTANTTHIS ROUTINE FUNCTIONS IN CONJUNCTION WITH FX30, WHICH MAINTAINS A PERIODIC TRIGGER OUT OF DIG OUTPUT 2 (BIT 0) SO THAT THERE IS A RASTER EVEN WHEN THIS ROUTINE IS NOT RUNNING. THIS ROUTINE WILL NOT WORK UNLESS FX30 IS RUNNING

SPACE LIST MUST BE 4096. WORDS LONG AND BE OF 12-BIT AMPLITUDE SPATIAL FREQUENCY IS THE NUMBER OF CYCLES ACROSS THE SCREEN WITH A SPATIAL RESOLUTION OF 256. POINTS. THAT IS, ONLY 256 OF THE 4096 WORDS IN THE SPACE LIST ARE OUTPUT IN ANY FRAME (EACH POINT SKIPS 16 WORDS).

LUMINANCE CONTRAST ATTENUATION IS SPECIFIED IN 1/4 dB UNITS

AVG DRIFT FREQUENCY IS THE AVG PHASE OFFSET BETWEEN FRAMES (1 CY = 4096. VIRTUAL POINTS ACROSS THE SCREEN).

ACTUAL DRIFT FREQUENCY IN HERTZ IS EQUAL TO THE (DF PARAMETER/4096) * THE FRAME FREQUENCY.

ACTUAL DRIFT MODULATION IN HERTZ IS EQUAL TO THE (DM PARAMETER/4096) * THE FRAME FREQUENCY.

THE DRIFT MODULATION WAVEFORM MUST BE 512. WORDS LONG AND OF 16-BIT AMPLITUDE. (UNDER NORMAL CIRCUMSTANCES, THIS IS A SINE LIST)

DRIFT MODULATION IS SPECIFIED AS THE PEAK AMPLITUDE OF DRIFT IN UNITS OF PHASE OFFSET.

DRIFT MODULATION FREQUENCY IS THE NUMBER OF CYCLES OF DRIFT MODULATION PER 512 FRAMES.

ACTUAL DRIFT MODULATION FREQUENCY IN HERTZ IS EQUAL TO THE (DMF PARAMETER/512) * THE FRAME FREQUENCY.

1 KHZ DIVIDED BY THE INTERVAL PARAMETER OF FX30 IS THE FRAME RATE. ENTERING ZERO FOR FRAMES LETS THE DISPLAY FREE RUN UNTIL A KEY IS TYPED AT THE TERMINAL.

ELECTRICAL CONNECTIONS:
DACY -> ATTENUATOR 2 INPUT
ATTENUATOR 2 OUTPUT -> Z-AXIS INPUT OF DISPLAY CRT
BIT 0 OF DIG OUTPUT 2 TO SWEEP (RAMP) TRIGGER OF
X AXIS OF DISPLAY CRT.
RASTER (TRIANGLE) TO Y-AXIS OF DISPLAY CRT

FX(21,BUFFER,ADDRESS,NUMBER OF POINTS):

RANDOMIZES THE ORDER OF N POINTS AND RETURNS A LIST N POINTS LONG CONTAINING SHUFFLED VALUES FROM 1 - N

N MUST BE LESS THAN OR EQUAL TO 256

FX(30,INTERVAL):

AUXILIARY ROUTINE NEEDED BY CSICK TO TRIGGER RASTER EVE WHEN DISPLAY IS OFF

STARTS THE CLOCK RUNNING AT 1 KHZ/INTERVAL RATE, AND OUTPUTS A PULSE THROUGH BIT ZERO OF DIGITAL OUTPUT 2. CALLED WITH NO INTERVAL ARGUMENT, TURNS OFF THE CLOCK

SINE12.512, SINE16.512:

These are lists of integers forming sine waves of 12- and 16-bit amplitude, respectively. The 12-bit list is needed because the D/A which controls the luminance across the CRT screen has only 12 bits of resolution. The 16-bit list is the one which controls the velocity modulation. It must be 16 bits to give the best velocity modulation resolution. See FX413.MAC for further details. Oh yes, you can replace these lists with those of any desired spatial or velocity modulation waveform, provided they are of the proper amplitude, and have a length of 512 words.

Block 's and their functions:

0 Erases unneeded fx routines and loads the new ones. But nsetup's block 0 erases the above, and replaces it with a restart query.

1 Library gets nsetup,loads space and velocity modulation lists, asks for frame period, subject and session.

2 Exit routine, called by main menu block (5). You must exit by either the "2" option or by a "DO 2". Otherwise the clock will continue to interrupt, but there will be no program code to service that interrupt.

3 This is called by the main menu as the "display stimulus" option.

4 This is called by the main menu as the "Do experiment" option.

5 This is the main menu block. Line 5.1 is also called throughout the program to clear the screen of the PT100

16 This block prints out the stimulus parameters for a given stimulus , and allows you to alter any parameter of that stimulus. It is used by block (option) 3 and by block 18 in creating and modifying stimulus parameters.

18 This block controls the creation and calling up of parameter files.

19 This opens some of the output files, and also opens up a file called CH.FCL which holds the "brief description of your experiment". This file is appended to the top of the ".Q" file created by the program, and then is deleted, so you may never actually see CH.FCL

25 Executes a trial

30

31 Controls execution of one trial (D 25)

33 Feedback tones

34

35 Determines whether to increase or decrease VMA from the number of previous reversals.

36 Halves step size.

37 Stores VMA if to be presented in second window

38 Rings long bell at end of experiment.

46 Writes .R file (contains all variables for current run)

49 Blanks old parameters between trials

50 Computes means and SEs.

52 Types data summary:

```
stim1   stim2   ...

0:0     0:1     (correct/incorrect:VMA)
```

VARIABLES:

CH	(46,30)	
CH(I)	(19,15)	Description of expt (virtual text)
CN	(18,22)	number of columns
CP	(18,37)	Column parameter
C1	(35,10)	Temp store for VMA when noise is first
H	(5,10)	
IS	(4,20)	Initial step size
IN	(4,30)	
J	(5,10)	
LS	(4,20)	Final step size
LC	(35,10)	
M(S)	(50,10)	Mean of S
M1(S)	(46,25)	
N(1	(49,10)	Number of valid repeats (ignores initial trials)
NR	(4,20)	Number right for decrease
NR()	(4,25)	Number right (each stimulus)
NW	(4,20)	Number wrong for increase
NR()	(4,20)	Number wrong (each stimulus)
O	(16,10)	Offset (bytes) into parameter block 64*stimulus *
PA	(18,10)	Name (?) of parameter file
PT	(18,10)	
PI	(1,20)	Frame period

PC	(49,10)	
PT	(18,12)	"Previous trial"
P()	(18,35)	Parameter
PR	(18,12)	
Q	(4,25)	? # of repeats of stimulus
Q8	(18,19)	"Parameter value"
QM	(18,21)	"Matrix"
RR	(4,10)	
RS	(18,22)	Response value (1 or 2)
R()	(4,25)	
RN	(18,22)	# of rows in Matrix
RP	(18,37)	"Row parameter"
RE	(31,10)	# of repeats in parameter file
S	(3,10)	? Stimulus
SU	(1,20)	Subject #
SE	(1,20)	Session #
SS	(4,25)	? # of stimuli
ST	(4,25)	Step size
SX	(50,10)	Squared sum
TC	(4,25)	? This DELTA (stimulus #)
TP()	(31,60)	? Counts # of part. stim repeated
TT()	(4,25)	? This trial
T1(,)	(4,40)	VMA(# of repeats, stimulus #)
U	(4,10)	? Counter
V	(16,20)	? Value

XX	(50.10)	Sum of squares
Z	(18.40)	? Dummy counter
ZZ	(3.10)	

RUNNING CSICK

ASSIGN DK, PAR, DAT (@CSICK)

TURN ON POWER SUPPLIES (ALL 3)

CONNECT SWITCH (DISCONNECT FROM JANETS ROOM)

CHECK ALL OTHER ELECTRICAL CONNECTIONS

DON'T FORGET TO RENAME NEW PARAMETER FILES

Parameter value/Computer unit Equivalences:

SF:	c/deg	units
	.5	2
	1	5
	2	10
	4	20
	8	40

DF:	Hz	units
	.5	16.4
	1	32.77
	2	65.54
	4	131.08
	8	262.16

VM:	Hz(peak)	units
	.1	3.29
	.5	16.4
	1	32.78
	2	65.55
	4	131.07
	8	262.13
	10	327.68

AT:	%C	units
	10	80
	20	56
	30	41.8
	40	31.8
	50	24.1
	60	17.75
	70	12.40
	80	7.75
	90	3.36
	100	0

VF:?	Hz	units
	.244	1
	.488	2
	.5	
	.977	4
	1	
	2	
	2.44	10
	4	
	6.?	25

END

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DTIC